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Design of Domestic Helix Vertical Axis Wind Turbine to Extract Energy from Exhaust Fans

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Abstract
The application of wind energy in power generation is increasing day by day. Horizontal axis wind turbines (HAWT) are considered more efficient than vertical axis wind turbines (VAWT) but with urbanization and limited access to wind in cities, VAWT may offer greater advantages, as HAWT are generally used in wind farms as large wind turbines. In many high altitude regions, average wind velocity is around 5-8ms^{-1} which can be utilized for electricity production, but in cities, that are at lower altitudes and are congested, the kinetic energy of exhaust fans can be used for electricity production. This paper describes the design of VAWT that can be used to generate electricity at domestic level using the energy from exhaust fans.
Keywords: Vertical Axis Wind Turbine (VAWT); Wind Energy; Design model; Innovation.

1. Introduction

Many meteorological and topological regions in the world are conductive to level of wind velocities suitable for power generation. The kinetic energy of the wind varies with factors like latitude, altitude, seasons and geographical locations. The world is on the verge of scarcity of energy resources and most of the resources used are basically non-renewable sources of energy. Reduced availability of fossil fuels and limited capacity of the world to cope with the pollution caused by fossil fuel are the two major considerations that have forced the world to seek an alternative energy system. Power generation through wind is one of the most attractive solutions for safe and clean renewable energy resources. In recent years, the focus on wind energy has increased significantly for the shortage of resource and climate change [1]. European Union had set a biding target of a 20 percent renewable energy contribution by 2020, and it was estimated that wind energy could contribute one-third of this production [2]. However, wind power occupied less than 0.7 % of the 16% renewable energy resource in 2009 [3], indicating that there was a broad prospect for wind power. There are some rural areas having abundance of wind energy but are still facing the problem of electricity. Therefore, the wind energy can be a proper solution for these types of areas, rather than fossil fuels [4]. Wind power is now the world's fastest growing energy resource [5]. According to an estimate there is a worldwide annual potential, with power of 10 KWH or 3.6 GJ. The available wind power possesses a huge potential that can contribute 5 times the world energy demand and contribute 0.4% of the huge sum of total energy.

This work is an outcome of the motivation, to utilize the wind energy for electricity generation and to fulfill the needs of the rural residents. Small wind turbines are easy to install and affordable, and can easily provide enough electricity to power a home, business, or farm. HAWT are in focus of all wind energy related research activity for last few decades. However, research on VAWT is continued in parallel at a relatively smaller scale. Scientists and Engineers developed various wind turbine configurations and utilized different approaches for their analysis and determined the optimum conditions for the working of VAWTs. A closer look on the concepts leads towards the fact that VAWTs are suitable for electricity generation in the conditions where traditional HAWTs are unable to give reasonable efficiencies such as high wind velocities and turbulent wind flows. Another major advantage is that VAWTs are omni-directional, accepting wind from any direction without any yawing mechanism [6-10].

The major advantage of VAWTs is that being a standalone system it can be used at any location [11]. Even if an area that does not receive much consistent wind, one can still harvest energy from the air currents with a helix wind turbine. Straight, untwisted and uniform section blades of VAWTs are easy to fabricate and give the performance that is comparable with HAWT, with almost 40% extraction of wind energy [12].

In this paper novel approach to extract the energy from exhaust fans using vertical axis wind turbine with helical blades is demonstrated. Not only it is capable of generating electricity constantly when an exhaust system is in operation but also reduce the power consumption by the exhaust air system. It is an energy recovery system and not intended to replace fossil fuel for energy demand of a country. However, this system enables the low wind speed countries especially in urban areas to harness wind energy from exhaust air resources which are consistent and predictable. The electricity generated from this system can be used for commercial purposes or can be fed into the electricity grid [13-15].

2. Materials and Methods

2.1. Design data Specifications

2.1.1. Domestic Helix Wind Turbine Specifications

Dynamo or D.C. motor maximum capacity (Voltage) = 50 volts
Height from the ground level = 600 mm
Motor diameter = 240 mm
Shaft diameter of motor = 6 mm

2.1.2. Principle of Wind Turbine

According to this theory kinetic energy of the wind can be used to produce the shaft power and hence the electrical power. Kinetic energy of wind = $½ \rho a V_i^3$; where 'a' is the area of blade exposed to the flowing wind (it may be treated as the rectangular area), 'ρ' is the density of air and 'V' is the incoming velocity of wind which has been taken as 5 ms^{-1} in the present study.
Power available in the wind is numerically equal to the kinetic energy of wind.

2.1.3. Maximum power

It is the fraction of total power that can be converted into useful work. At optimum velocity $V_e= 1/3\ V_i$; where 'V_e' and 'V_i' are exit and inlet velocities respectively.
For maximum power optimum exit velocity; $V_e= 1/3\ V_i$
Hence; $P_{max}=8/27\ \rho a V_i^3$
Ideal or maximum theoretical efficiency; $\eta_{max}= P_{max}/P_{total}$
$\eta_{max}= (8/12\ \rho a V_i^3)/ (½\ \rho a V_i^3) = 59.26\%$

2.1.4. Torque and axial thrust on the blade (T):

Due to circumferential force acting on the blade, torque is generated on the turbine.
$T_{max} = (P_{max}/ W) = (8/12\ \rho a V_i^3)/ (2лN/60) = 0.20$ N-m.
Where; N=120 rpm, V=5ms^{-1} and ρ=1.2kg/m^3
Area of blade exposed= a= $555*10^{-4}$
Axial Force= $F_x = 4/9\ \rho a V_i^3$ (at $V_e= V_i/3$)
Thus $(F_x)_{max}$ is directly proportional to the area 'a' and cube of the wind velocity 'V_i'

2.2. Performance of wind turbine

2.2.1. Coefficient of performance or power coefficient or maximum efficiency (COP) = Max. Power/Total Power = 0.5926

2.2.2. Tip speed ratio (λ) = blade tip speed/free stream wind speed=$V_b/V_i \approx 1$. Where; V_b= peripheral speed in case of vertical turbine

2.2.3. Solidity (γ) = blade area/swept frontal area ≈1(Rotor having high solidity use drag and turn slower)

	Tip speed Ratio (λ)	Solidity(γ)	Torque(T)
Savonius	1	1	High
Propeller	4.16	0.01 to0.1	Low
Vertical Helix	≈1	≈1	High

2.3. Design Parameters

2.3.1. Designing of Bevel Gear

Lewis equation -$W_T = \sigma_o C_v$лbmy'((L-b)/L)
Metre gear-When the two gears of same size have equal numbers of teeth and connect the two shafts at right angles to each other are known as metre gears.
For metre gears; $\theta_{P1} = \theta_{P2} = 45^o$ (V.R. = T_G/T_P = 15/15 =1, $\theta_{P1} = \theta_{P2} = \tan^{-1}(1/V.R.) = 45^o$)

Step1: Working stress

$\sigma_w = \sigma_o*C_v$
σ_o = allowable static stress(for gray cast iron)=56MPa
Velocity (V) =лD_pN_p/60 (N_p =120rpm and D_p =26mm)
V =л*26*120/60=163ms^{-1}
Velocity factor(C_v) =3/(3+V) = 3/(3+163)=0.947
$\sigma_w = \sigma_o*C_v$=56*.947=53MPa

Step 2:

Module(m) = D_P/T = 26/15 = 1.73 ≈ 2mm
Face width(b) = 8m = 8*2 = 16mm
Slant height(L) = $D_P/\sqrt{2}$ = 26/√2 = 18.38mm
Bevel factor= (L-b)/L = (18.38-16) /18.38 = 0.13

Step 3:

Lewis form factor, y' = .154 – (.912/T_{EP})
T_{EP} = T/cosθ_p= 15/cosθ_p= 21.2
y' = 0.154 – (0.912 /21.2) = 0.11

Step 4:

Tangential load (Lewis equation) = W_T= $\sigma_o C_v$лbmy'((L-b)/L)
W_T=σ_wлbmy'((L-b)/L) =53л*16*2*.11*.13=76.15 N

Step 5: Design Checking.

Dynamic load, $W_D = W_T + W_I$
Where; W_I= (21VC (b.C+W_T))/ (21V+√ (b.C+W_T))
Where; C = K_e/ (1/E_P+1/E_G)
E_P= E_G= 84*10^3MPa (for 20º full depth teeth)
K = 0.11, e = 0.05
C = 0.11*0.05/ (1/84*10^3+ 1/84*10^3) = 233 MPa
W_I= (21*.163*233(16*233 + 76.13))/ (21*.163 + √ (16*233 + 76.13))= 200 MPa
W_D=W_T+W_I = 76 + 200 =276

Step 6:

W_W= D_P*b*Q*K
σ_{es}= 630MPa
K= (σ_{es}^2*sinΦ/1.4) (1/E_P+1/E_G)= (630^2*sin20/1.4) (1/84*10^3+1/84*10^3)= 2.3MPa
W_W= 26*16*1*2.3 = 956.8 MPa (Q=1)
Hence; W_W>W_D
Therefore the design is safe.

Step 7: Checking for static load.

W_S= σ_eлbmy'= 84*3.14*16*2*0.11= 928.43 MPa
1.23 W_D= 1.23*276 = 345 MPa
Therefore; W_S>1.23W_D
Hence the design is safe from stand point to static load.

2.3.2. Bearing Design (Roller Ball Bearing)

Inner diameter, d=20 mm
F_r= Radial load
F_a= Axial load
Bearing Width = 12 mm
Series-02 (Light series)
N= revolution maximum
L_H= Life of bearing in hours in a year (assume) = 15 hrs
Shaft Diameter, D = 14 cm
w = 12 cm
D_i = internal diameter=1.9 cm
D_o= outer diameter=2.6 cm
No. of roller Balls = 11
Mass (m) = 400 gm = 0.4 kg
Radius = 15+0.85 = 15.85 cm = 0.158 m
N = 300 rpm (max)
W = 2пN/60 = (2*3.14*300)/60=31.4
Radial force, F_r = mrw^2 = 4*0.158*(31.4)^2= 62.3 N
Axial Force, F_a= mg = 0.4 * 9.8 = 3.92 N
L_{10}= (60n*L_H)/106 = (60 * 300 *15 * 360 * 15) / 10^6 = 1478.25 million revolutions
Trial series (O2) SKF bearing
Di = 1.5 cm = 15 mm
Static load capacity, C_o= 3750 N
Dynamic load capacity, C = 7800 N

Step I:

F_a/C_o= 3.92/3750 = 0.001045

e = 0.09

Step II:

F_a/F_s= 3.92/62 = 0.063

e >F_a/F_r

X = 1, Y = 0

P = ($X*V*F_r$+ $Y*F_a$) K*S = (1 * 1 * 62.3 + 0 * Fa) * 1 = 62.3 N

L_{10} = $(C/P)^P$[p=10/3] = (7800/62.3) ^ (10/3) = 9817973.4 million revolutions

L_{10}(theoretical) > L_{10}(given)

Hence the Design is safe.

Selected bearing in series 002 (SKF)

2.3.3. Spur Gear Design

No. of teeth = 15

Diameter, D_o= 2.6 cm

Addendum = 2.6 cm

No. of teeth on pinion, T_P= 15

No. of teeth on gear, T_G= 60

D_G= 5.2 cm ≈ 6 cm

Step 1: D_P= $(T_P*D_G)/T_G$ = (15*6)/60 = 1.5 cm

Applying Lewis equation, W_T= σ_w*π*b*m*y_p [σ_w= σ_o* C_V]

Non-metallic material

σ_o= allowable static stress = 50 MPa

C_V= velocity factor = 3

Step 2: Pinion Design:

V_p= π*D_p*N_p/ σ_1 [D_p= 150 mm]

N_p= gear ratio * N_G= 4 * 60 = 240 rpm [N_G= 60 rpm]

V_p= (π * 150 * 240) / 60 = 1.884 m/s

C_v= 3 / (3+1.884) = 0.625

y_p= 0.154 – (0.912 / 15) = 0.0932

Facewidth, b = 10*m = 10 mm [Module, m = D_p/T_p = 15/15 = 1]

σ_w= σ_o* C_V = 31.25 MPa

Put all the values in Lewis Equation, W_T= σ_w*π*b*m*y_p = 91.4525 MPa

Step3: Checking for dynamic & wear load:

Dynamic Load, W_D= W_T+W_I = W_T+ {21 V (b*C + W_T)} / {21 V + √(b*C + W_T)}

C = K_e/ (1/E_p+ 1/E_a)= (111*0.0925) / (1/0.42 + 1/0.42) = 2.15 * 10^{-3}N/mm

Thus, W_D = 162.12 MPa

Step4: Static Load: W_S= σ_e*π*b*m*y_p = 360336.54 MPa

For pulsating load, W_S≥ 1.35 W_D≥ 1.35 * 162.12≥ 222.91 MPa, which is true.

Hence the design is safe.

2.4. Model preparation

Mild steel rod with a length of 400 mm has been used for the main shaft. This rod was adjoined with a100 mm long spring for flexible rotation of rod. PVC clear pipe has been used for casing for showing clear working. The bearing was inserted in the rod from top of the spring and then PVC sheet covering was used as a first support. Then the bevel gear was used for transmitting vertical rotation to horizontal rotation. Then the dynamo was fixed with the horizontal shaft. Both the horizontal shafts were connected with spur gears. Plastic fiber sheet has been used as the blade material. The sheet was curved to give the special shape with the help of heater. Then after attaching the blades to the main shaft, a multimeter was attached to the dynamo to check its output. As per the proposed design, 3-12 V output can be generated, however the output may vary with the wind speed.

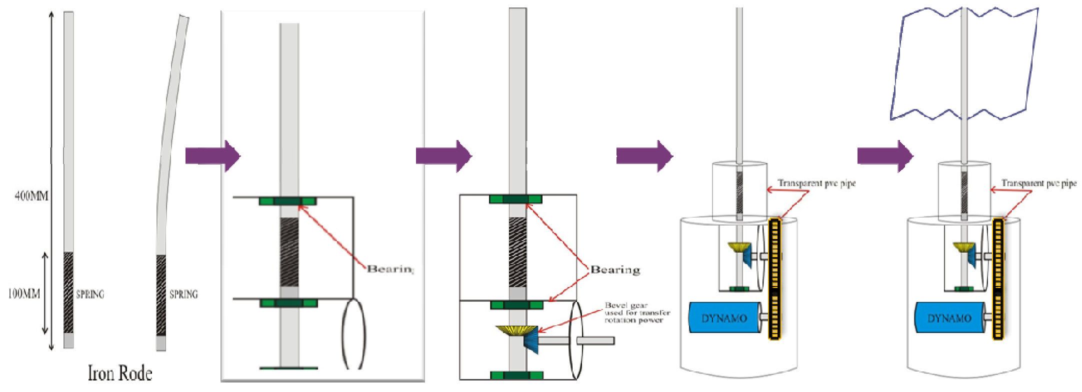

Fig. 1. Steps of model preparation

3. Results

1. Maximum efficiency of the model was found to be 59.26%.
2. Maximum torque of the domestic helix VAWT was 0.20 N-m.
3. Despite the very simple construction, the performance was found to be surprisingly good, with a maximum measured C.O.P. value of 0.5926.
4. Since $W_W > W_D$. Therefore the design of the VAWT is safe.
5. Since $W_S > 1.23W_D$. Hence the design is safe from stand point to static load.
6. Since L_{10}(theoretical) > L_{10}(given). Hence the overall design is safe.

Fig. 2. Final designed model of Domestic Helix Vertical Axis Wind Turbine

4. Conclusions

The wind turbine extracts energy by slowing the wind and transferring this energy to a spinning shaft, which turns generator to produce electricity. The power in the wind that is available for harvest depends on the wind speed and the area swept by the turbine blades. Designing of the domestic helix wind turbine is safe and it can be easily installed in houses. The model designed in this work is safe and despite the very simple construction, the performance was found to be surprisingly good, with a maximum measured C.O.P. value of 0.5926. Maximum efficiency and maximum torque of the model was calculated as 59.26% and 20 N-m respectively.

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